International Journal of the Physical Sciences Vol. 6(4), pp. 730-745, 18 February, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS10.616
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Long term behaviour of a retaining wall resting on clayey soil

Firas A. Salman[1]*, Mohammed Y. Fattah[2], Dunya K. Sabre[2]

Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.
[2]Department of Building and Construction Engineering, University of Technology, Baghdad, Iraq.

Accepted 27 January 2011

The magnitude and distribution of lateral earth pressure acting on a retaining wall due to dry cohesionless backfilling material and existence of saturated consolidated clay in the foundation are studied by a series of two-dimensional plane-strain analyses. For the particular wall geometry and soil condition, effects of wall height and elapsed time of consolidation are investigated and discussed. The analysis was carried out using the finite element computer program, CRISP, with some modifications to cope with the objective of the analysis. The behaviour of the concrete retaining wall is represented by a linear elastic model. The backfilling material was assumed to be elasto-plastic with Mohr-Coulomb failure criterion, while the clay foundation is assumed to follow Cam-clay model. The thin layer interface element is used to represent the interface between the wall and the surrounding soil. The results showed that the wall tilted towards the backfilling material during consolidation. Also, it was found that the permeability and Poisson's ratio of the foundation soil are the most important material parameters that influence the behaviour of the retaining wall.

Key words: Consolidation, finite elements, modified Cam-clay, plane strain, retaining wall.

INTRODUCTION

Soil-structure interaction analysis has been proven to be powerful tools for analyzing, designing and monitoring geotechnical structures. During the last few decades several geotechnical research works dealt with the development and improvement of techniques for soil-structure interaction analyses of retaining walls, piles, anchors, etc.

Experience with the application of the finite element method in the analysis of stresses and displacements of earth masses have shown the importance of modelling the actual construction process as closely as possible with the inclusion of a nonlinear stress-strain soil model. Application of this procedure to soil-structure interaction problems led to the additional requirements that the soil backfill and the interface elements be incorporated within the finite element mesh.

For permanent structures in clayey soils it is essential that account is taken in design of conditions in both the short-term, during and immediately after construction, and in the long-term when full equilibrium has been achieved. Which of these proves the more critical depends on whether the ground has been subjected to a net increase or decrease in stress by the construction of the retaining wall. For example, the critical condition of stability of a cantilever or gravity wall retaining granular backfill and founded on a soft clay subsoil is likely to occur in the short-term, while vertical deformation and settlement will be greater in long term. Conversely, for an in situ wall embedded in stiff clay the stability is likely to decrease, and lateral deformations are likely to increase with time. This is associated with softening and swelling of the ground that occurs in response to the reduction in stress caused by excavation in front of the wall.

In cohesive soils the earth pressures and deformations occurring in the short-term are frequently assessed from a total stress calculation using undrained soil properties.

*Corresponding author. E-mail: firasalman@hotmail.com.

An inherent assumption of this approach is that no change in these properties occurs during the construction period. For many cohesive soils that contain discontinuities or more permeable seams within their mass, this condition is unlikely to prevail in practice. Particular care is therefore necessary in the use of such methods where deteriorations in soil properties with time is anticipated, such as in the case of temporary works involving an in situ wall in stiff fissured clay (Skempton and La Rochelle, 1965).

The long-term earth pressures and deformations in cohesive soil are calculated from effective stress analysis. Such analyses can also be used to assess conditions in the short-term but require information on the pore water pressure regime in the ground, which is more difficult to assess in the transitory state prior to the establishment of an equilibrium pattern of groundwater flow.

LITERATURE REVIEW

Procedures for the finite element analysis of conventional, stable earth retaining structures are well established. They have been successfully applied to the evaluation of the soil-structure interaction for a variety of earth retaining structures during the past decades, including U-frame locks, gravity walls, and basement walls (Ebeling, 1990).

Matsuo et al. (1978) investigated the characteristics of the earth pressure acting on a retaining wall on the basis of the large scale prototype tests in a field. They built a 10 m high concrete wall with silty sand and slags as backfill materials in order to study the influence of displacement of the wall on the magnitude and distribution of earth pressure in the vertical direction. Based on the results obtained from the tests, they proposed that a general retaining wall should be designed against the earth pressure at rest. They also compared the measured earth pressures with the analyzed results obtained by the finite element method. The soil was represented as a linear elastic material with triangular elements. They found that the influence of the unit weight (γ_t) and Young's modulus (*E*) on the calculated results are very small. That is, it is enough in the engineering sense to use the rough values of γ_t and *E* in the calculation of earth pressure at rest, but the calculation is very sensitive to variation in the value of Poisson's ratio.

Potts and Fourie (1984) carried out a numerical study about the behaviour of a propped retaining wall. In their study, the finite element is used to investigate the influence of type of construction (excavation or backfilling) and the initial stress in the soil on the behaviour of single propped retaining walls. A linearly elastic-perfectly plastic with a Mohr-Coulomb yield surface is used to model the soil behaviour, while the wall is assumed to be linearly elastic and a rigid propped is assumed to act at the top of the wall. The problem was solved as a plane strain condition with eight-noded isoparametric elements. The following conclusions may be drawn from this work:

The limit equilibrium method used in current design procedures produces reliable estimates for the depth of wall embankment required to maintain stability.

For excavation of walls in soils with a high value of coefficient of earth pressure at rest condition (K_o), prop force and wall bending moments greatly exceed those calculated by using the simple limit equilibrium approach. In addition, large soil and wall movements are experienced even at shallow depths of excavation. The behaviour is dominated by the vertical unloading caused by excavation process and large movement still occurs even if the wall is fully restrained from horizontal movement.

For backfilled and excavated walls in soils with a low (K_o) values, the analyses indicate that the displacements are much smaller in magnitude and that the approximate limit equilibrium calculations produce conservative values of prop force and bending moments.

Large zones of failed soils, especially in the front of the wall, are predicted for excavation walls in high (K_o) soils, and the lateral wall pressures behind the wall differ substantially from the classic active distribution. Passive conditions in front of the wall are completely mobilized at small excavation depths and before active conditions are approached down the back of the wall. In contrast, excavated walls and backfilled walls in low (K_o) soils show lateral pressures which are in agreement with the classical distributions.

Potts and Fourie (1986) employed the finite element method to examine the influence of wall movement on the generation of earth pressure. The effects of wall translation, rotation about the top and rotation about the bottom of the wall have been investigated. An elasto-plastic constitutive law using Mohr-Coulomb yield surface has been used to model the soil behaviour. The following conclusions arise from their investigation:

The nature of the wall movement, whether translation or rotation, has an effect on the equivalent values of K_a and K_p for both rough and smooth walls.

The final values of K_a and K_p are essentially unaffected by the value of K_o or the distribution of Young's modulus in the soil.

The relative displacements necessary to mobilize active and passive conditions depend on the wall, initial K_p value and distribution of Young's modulus.

The mode of wall movement has a considerable effect on the distribution of earth pressure.

Bhatia and Bakeer (1989) performed a finite element analysis of 10 m high instrumented experimental wall resting on a hinged base that was tested by Matsuo et al. (1978) in order to discuss some factors that influence the results of a finite element idealization of the problem of earth pressure behind a gravity wall with dry, cohesionless backfill. The problem was modeled by two dimensional, isoparametric, quadratic and quadrilateral eight-noded elements. The material model used for the soil elements is a nonlinear elastic-perfectly plastic model with a Von-Mises yield criterion where a yield stress is input at different strain levels. A series of analyses similar to that of Clough and Duncan (1969) analyses were conducted for the boundary conditions ranging from a wall with zero displacement to the case where the crest of the wall was displaced.

They found that a finite element mesh with a backfill extending horizontally for four times its height and having a free lateral boundary, or six times its height and having a restrained lateral boundary is required to model a gravity wall retaining a dry, cohesionless backfill. Fine elements should be used in the backfill behind the wall-back in region extending horizontally a distance of at least the height of a wall for the active case. The number of rows of the finite elements in the vicinity of the wall should be increased as much as possible to increase the accuracy in locating the earth pressures resultant.

It can be concluded that most studies concentrate on short-term analysis of retaining walls, a small attention was paid to the behavior of the wall during consolidation stages of the foundation soil. So, this paper is directed towards time-dependent analysis of a retaining wall.

TWO-DIMENSIONAL FINITE ELEMENT COMPUTER PROGRAM

The computer program used in the analyses is primarily based on a program provided by Britto and Gunn (1987) named CRISP (Critical State Program). The program uses the finite element technique and allows predictions to be made to ground deformation using critical state theories.

Program capabilities

Types of analysis: Undrained, drained or fully-coupled (Biot) consolidation analysis of two-dimensional plane strain or axisymmetric (with axisymmetric loading) solid bodies.
Constitutive models: Anisotropic elasticity, inhomogeneous elasticity (properties varying with depth), critical state soil models (Cam-clay, and modified Cam-clay).
Element types: Linear strain triangle and cubic strain triangle (with extra pore pressure degrees of freedom for consolidation analysis).
Non-linear techniques: Incremental (tangent stiffness) approach.
Boundary conditions: Element size can be given prescribed incremental values of displacements or excess pore water pressures. Loading is applied as nodal loads or pressure loading on element sides. The program performs automatic calculation of loads simulating excavation or construction where elements are removed or added.

Some modifications are made to the main finite element computer program (CRISP) to obtain the present computer program (Mod-CRISP) in order to achieve the computations needed in the present study. Certain modifications are incorporated to make the program able to cope with the problem of wall-soil system. The most important modifications are as follows:

i) The use of eight-noded quadrilateral isoparametric element with 16-d.o.f. (each node has 2-d.o.f.).
ii) The use of eight-noded quadrilateral isoparametric consolidation element with 16-d.o.f. and additional 4-d.o.f. on corner nodes, namely for excess pore water pressure.
iii) The use of thin-layer interface element developed by Desai et al. (1984).
iv) The use of Mohr-Coulomb model with elasto-plastic failure criterion.

Geometry and material properties

The problem considered in this study consists of a retaining wall, backfilling material, foundation soil and interface elements between the wall and the adjoin soil. The material properties of the foundation soil are those of the MIT test embankment, Table 1. The material properties of the concrete retaining wall are the same as those given by Gourvenec and Powrie (1999). Poisson's ratio used for the wall was (0.15) with Young's modulus equal to (25000 MPa) and unit weight of (24 kN/m^3). The properties of the backfilling material and the interface element are shown in Table 2. The geometry selected for investigation is shown in Figure 1.

Table 3 summarizes the numerical models used in the present study. The backfilling material is assumed to be elasto-plastic with a Mohr-Coulomb yield surface. The non-associated flow is used to represent the plastic flow. The drained condition is assumed and the calculations, therefore, represent a long-term solution.

The modified Cam clay model was used to model the clay foundation. The concrete retaining wall is assumed to be isotropic elastic material. No failure criterion was specified as it was anticipated that the in-service stresses in the concrete would be small in comparison with those that would cause failure (Gourvenec and Powrie, 1999).

Finite element mesh and numerical modelling

The 2-D finite element mesh used in the analyses is shown in Figure 2. The mesh represents a retaining wall supporting a backfilling material while it is supported by a clay foundation. The boundary was positioned far enough away behind the wall (a

Table 1. Material properties for the foundation clayey soil, (D'Appolonia et al., 1971; McCarron and Chen, 1987)

Material properties	Values
Poisson's ratio, ν	0.35
Slope of the critical state line, M	1.027
Slope of the normal consolidation line, λ	0.165
Slope of the swelling line, κ	0.06
Initial void ratio, e_o	0.9
Coefficient of permeability, $k^{\dagger}$ (m/day)	$6.252\text{x}10^{-4}$
Total unit weight of the soil (kN/m^3)	18.07

† from Lambe and Whitman (1979).

Table 2. Material properties for backfill, retaining wall and interface (Gourvenec and Powrie, 1999).

Parameter	Units	Material		
		Soil	Interface	Wall
E	kN/m^2	$5.5\text{x}10^4$	$5.5\text{x}10^4$	$28*10^6$
ν	-	0.2	0.2	0.15
c	kN/m^2	0	0	-
Φ	degree	25	25	-
G	kN/m^2	-	250	-
γ	kN/m^3	20	20	24

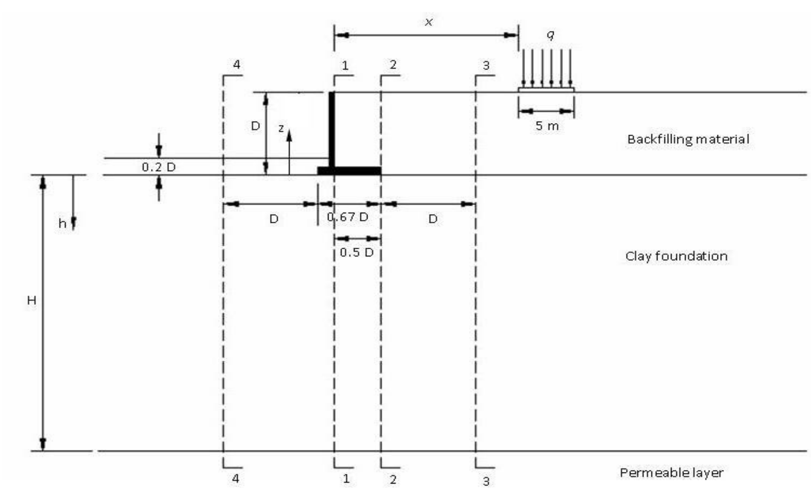


Figure 1. Problem geometry.

Table 3. Numerical and constitutive modes used in the study.

Material	Model
Clay foundation	Modified Cam-clay
Retaining wall	Isotropic elastic
Backfilling material	Mohr-Coulomb
Interface	Thin layer element

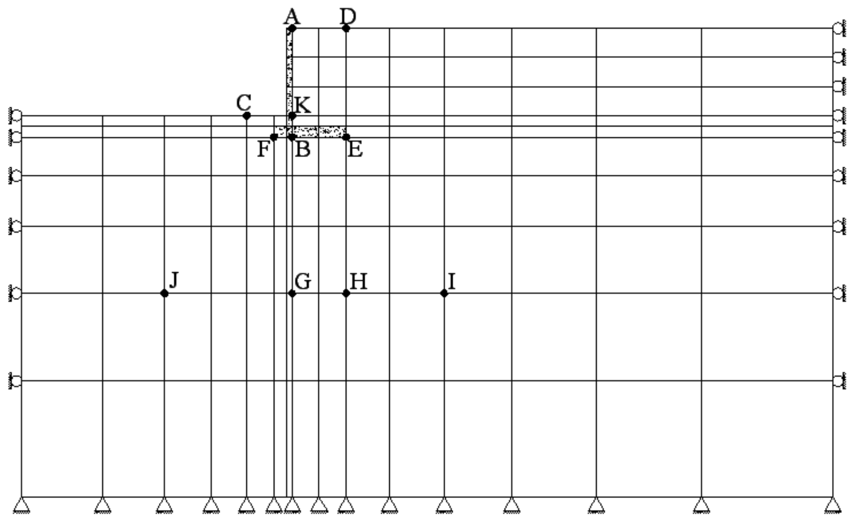


Figure 2. Typical finite element mesh used in the present study (Not to scale).

distance not less than five times the wall height as suggested by St. John (1975) and Bhatia and Bakeer (1989). This treatment does not affect the behaviour of the wall.

ANALYSES

A series of finite element analyses were carried out to investigate first, the effect of wall height (backfilling height) on the behaviour of a wall-soil system. Three wall heights were taken (5, 7 and 10 m). Secondly, the effect of variation of Poisson's ratio and permeability of the clay foundation during the time of consolidation was investigated.

The analyses were carried out for a period of 15 years. The wall was first constructed and the backfilling material is then placed by staged sequence with time in order not to cause a sudden increase in the excess pore water pressure.

Effect of backfilling on the behaviour of retaining wall

Lateral wall movement

The lateral wall movement is shown in Figure 3. It can be noticed that the wall is translated horizontally (towards the passive side) and rotated about a certain point in its height, and the location of this point depends on the wall height. This point is at about (0.6 D) (D is the wall height) from the wall base when the wall is (5 m) high and it is about (0.1 D) from the wall base for (7 m) high while for the wall of (10 m) height, there will be a clear translation during the consolidation time until it reaches the final stages of consolidation, the point of rotation will be at the base of the wall. In Figure 3, the negative sign is used to represent the wall movement towards the passive side.

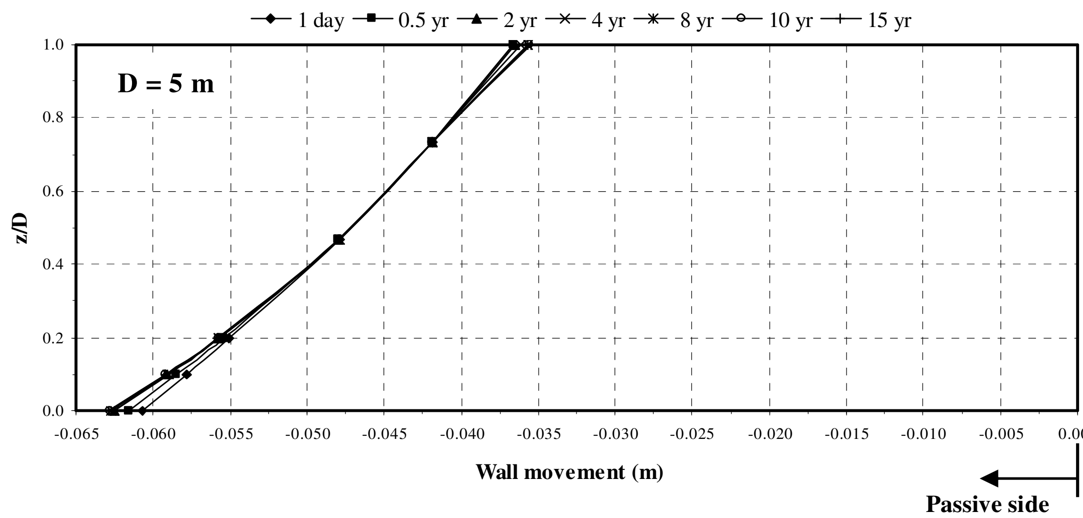
Settlement of the wall base

The settlement of the wall base for the three wall heights during all stages of consolidation is shown in Figure 4. It is obvious that the wall undergoes a differential settlement differing in value depending on the height of fill. In general, the differential settlement will not cause a slope greater than (0.7°) for all wall heights, which can be considered negligible. The higher values of settlement are expected due to the high compressibility of the foundation layer.

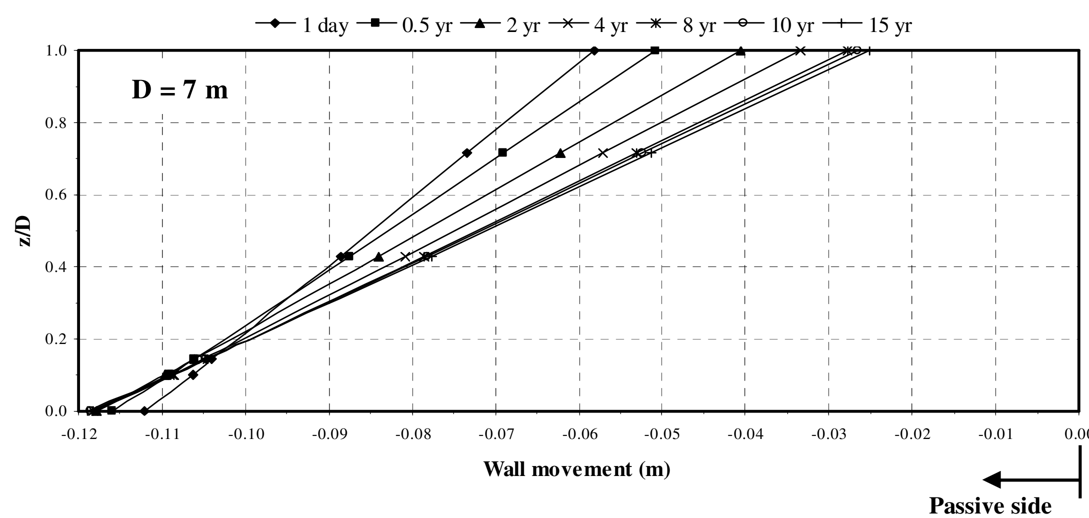
Resultant and location of earth pressure

The earth pressure behind the wall in its active side is shown in Figure 5 for the three wall heights and at different times. For (D = 7 m) and (D = 10 m), the active earth pressure will increase with time, while for (D = 5 m), the active earth pressure will decrease with time. The increase in the pressure distribution behind the wall is due to the settlement of the foundation soil and rotation of the wall towards the backfill which cause an increase in the active pressure distribution with the increase of the wall height.

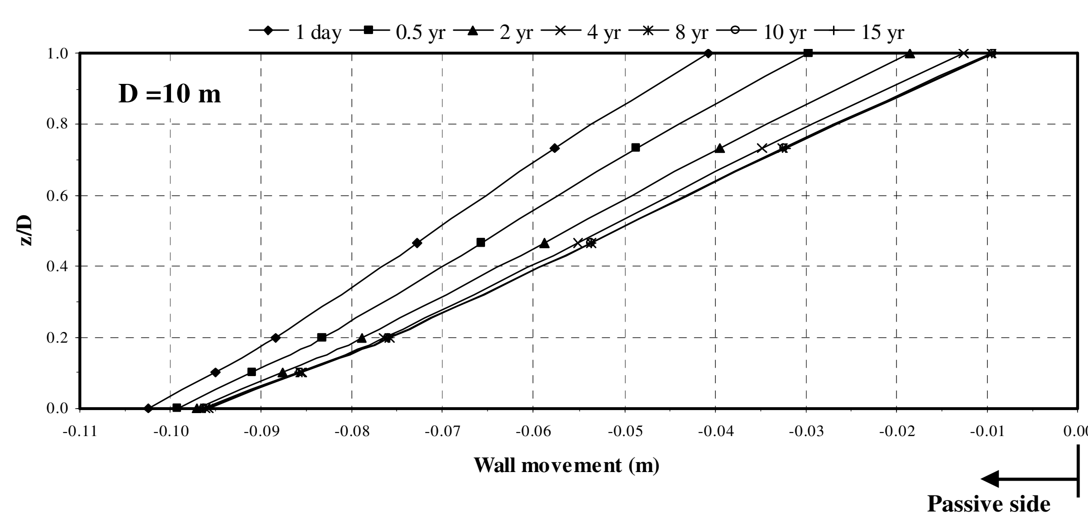
Figure 6 shows the change in resultant earth pressure with time. For (D = 7 m) and (D = 10 m), the earth pressure resultant will increase with time until it reaches a constant value after about four years, while for (D = 5 m), the earth pressure resultant will decrease with time until it reaches a constant value after six years. The percent of increase or decrease in the value of the earth pressure resultant is shown in Table 4.



(a): wall height is 5 m.

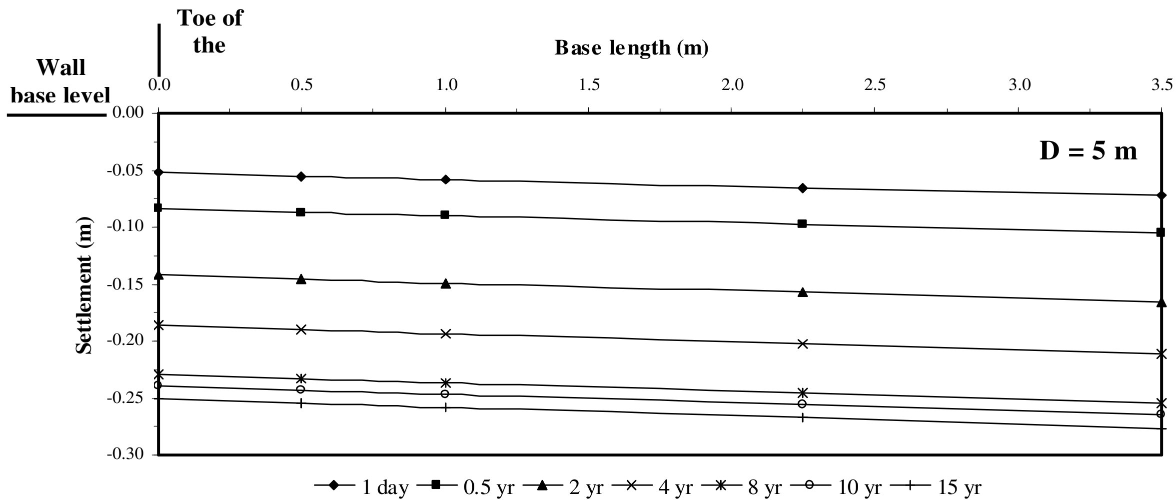


(b): wall height is 7 m.

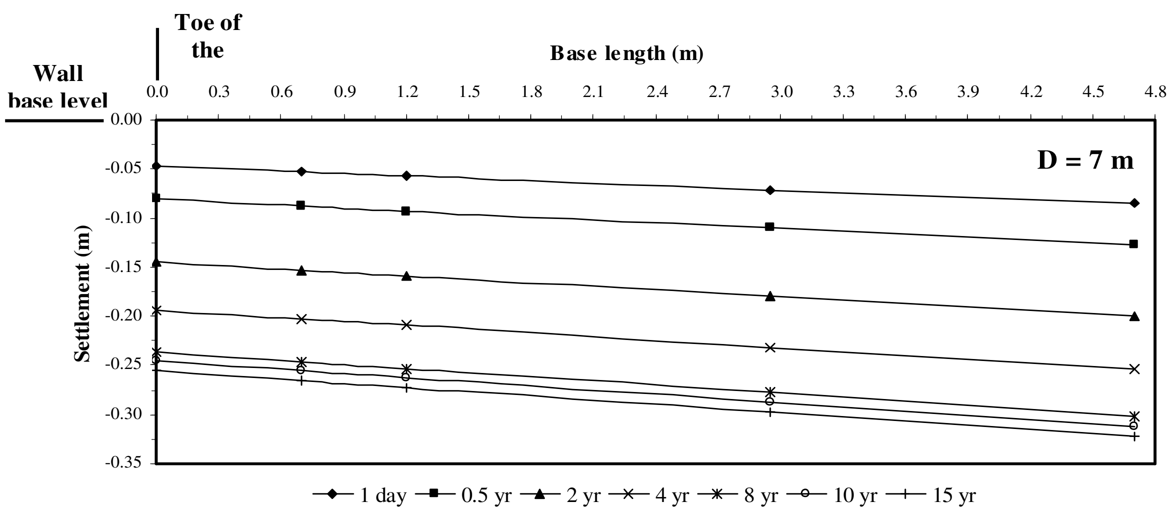


(c): wall height is 10 m.

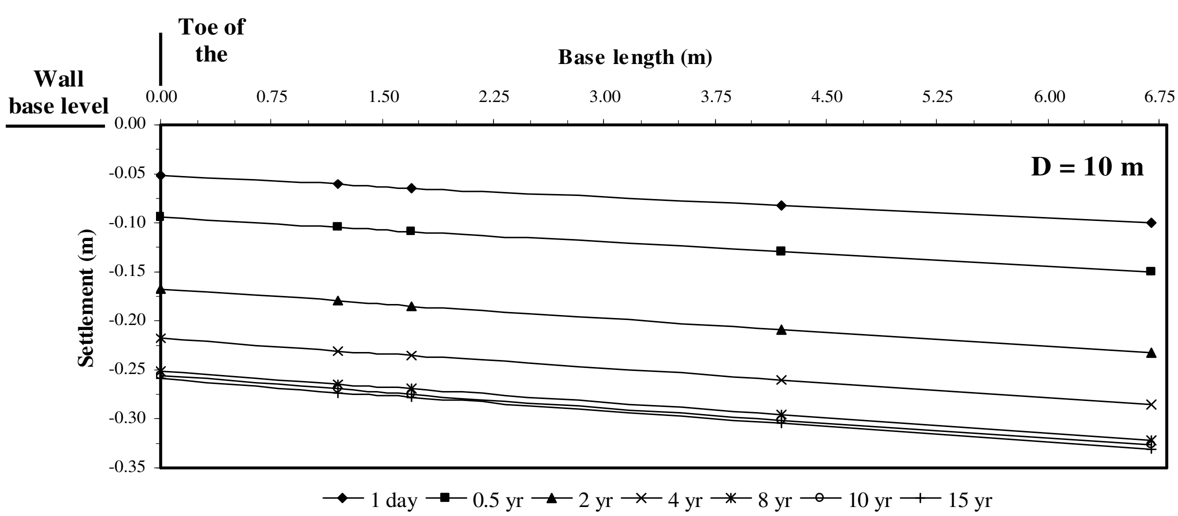
Figure 3. Lateral wall movement during the time of consolidation for different wall heights.



(a): wall height is 5 m.

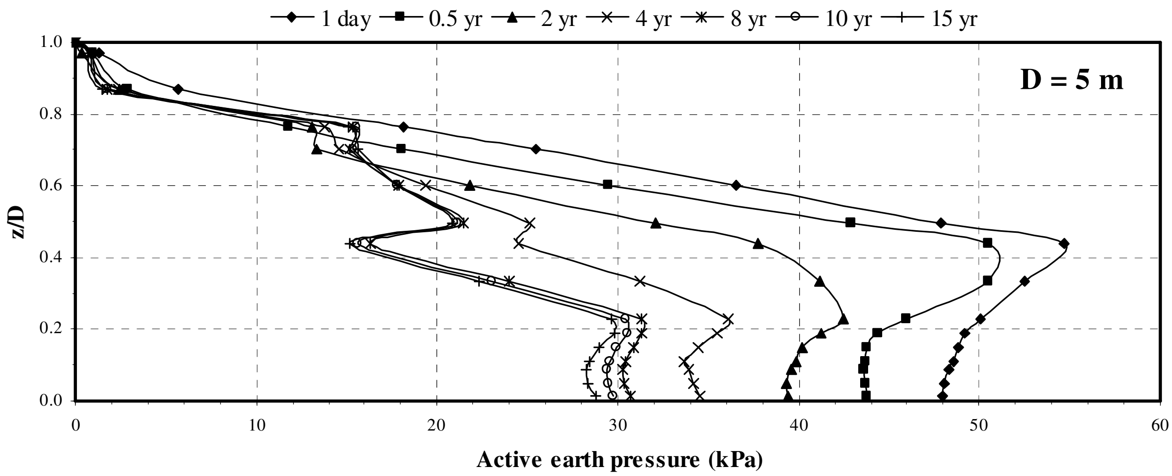


(b): wall height is 7 m.

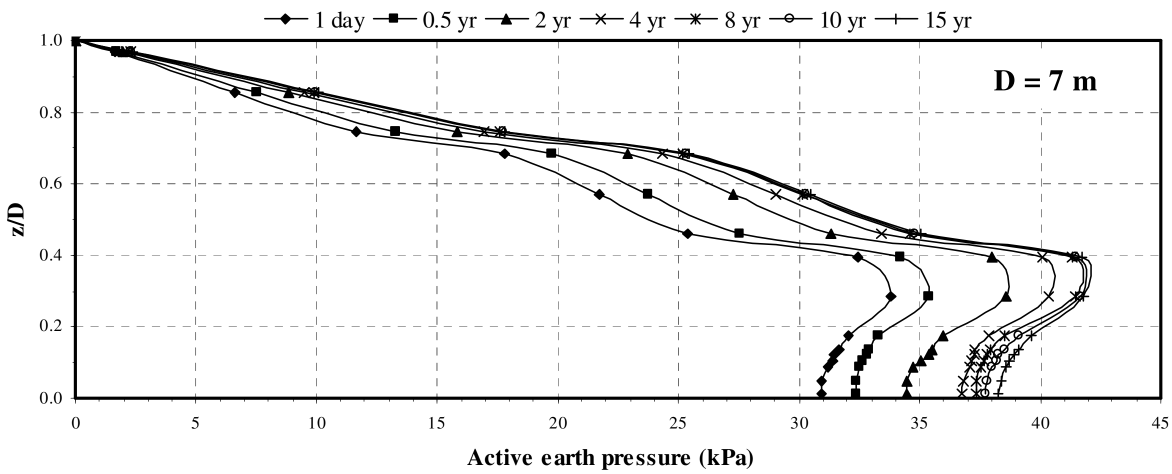


(c): wall height is 10 m.

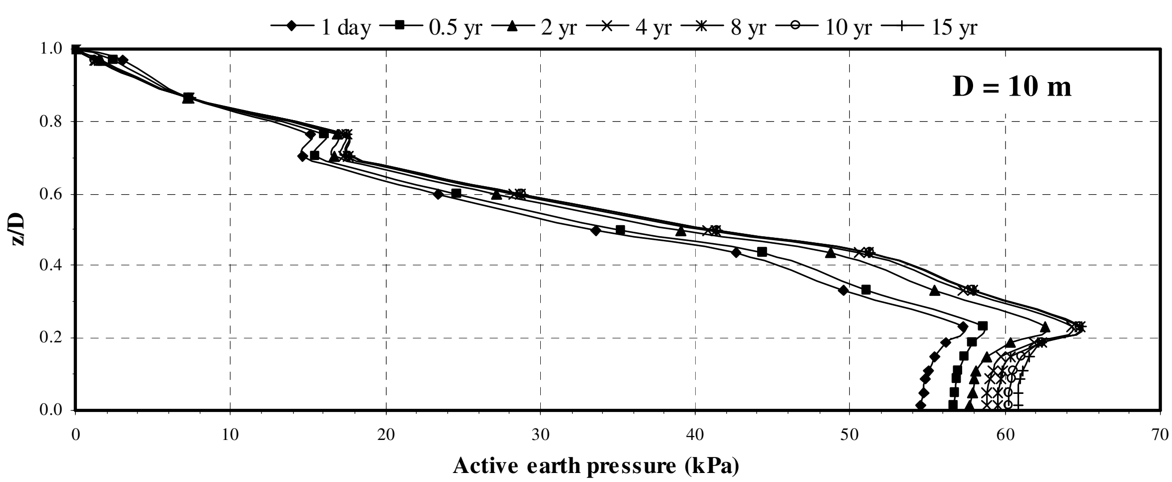
Figure 4. Settlement of the wall base during the time of consolidation for different wall heights.



(a): wall height is 5 m.



(b): wall height is 7 m.



(c): wall height is 10 m.

Figure 5. Active earth pressure behind the wall during the time of consolidation for different wall height.

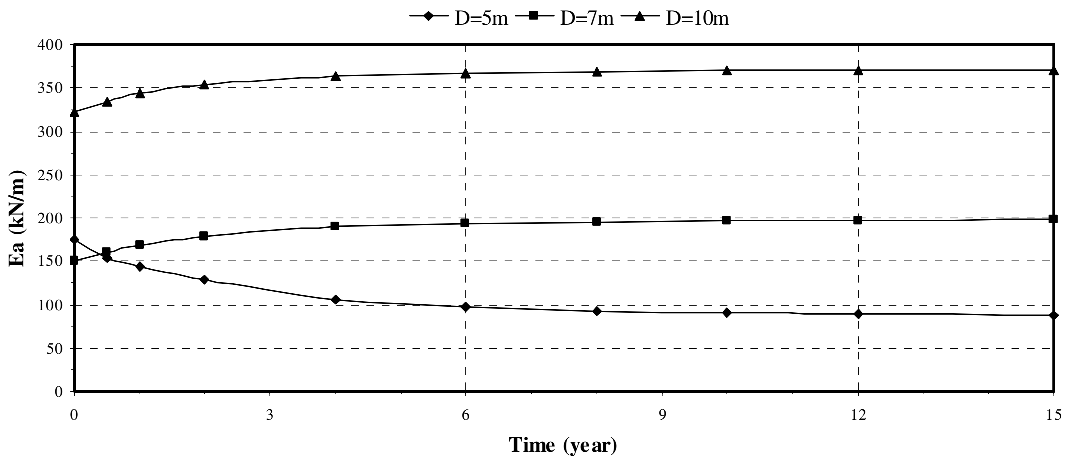


Figure 6. Resultant earth pressure verus time for the wall heights.

Table 4. Change in the resultant earth pressure (kPa).

Wall height (m)	Initial value	Final value	%
5	150.875	86.304	- 42.8
7	140.090	183.607	+ 31.1
10	308.924	349.716	+ 13.2

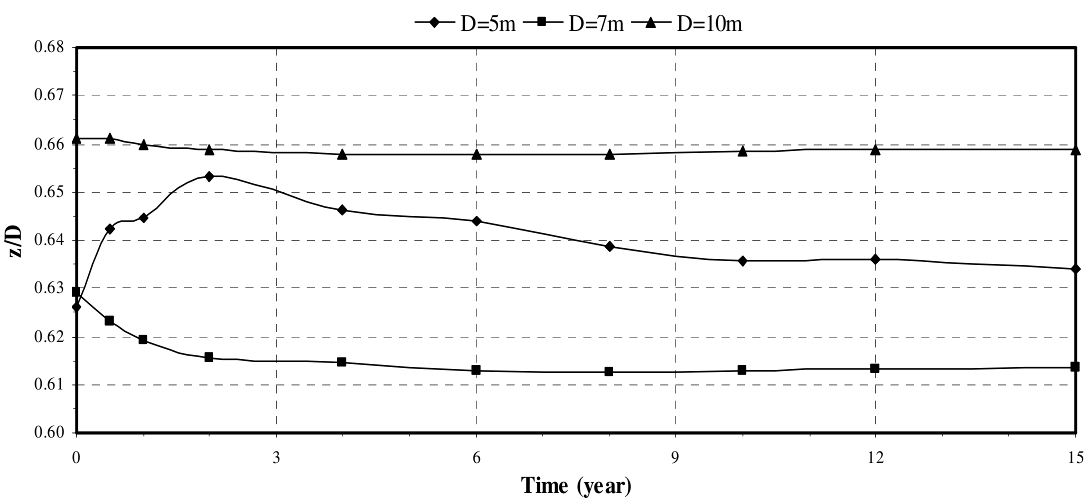


Figure 7. Location of the earth pressure resultant versus time the wall heights.

In the classical theories of the lateral earth pressure, the location of earth pressure resultant is at (D/3) from the wall base. Figure 7 shows that the location of the pressure resultant is higher than that of classical theories. The location is found to be between (0.35 D) to (0.41 D) depending on the wall height and time. The percent of increase or decrease in the value of the location of the earth pressure resultant from the wall base is shown in Table 5.

Factor of safety against sliding and overturning

The factor of safety against sliding can be calculated as

Table 5. Location of the earth pressure resultant.

Wall height (m)	Initial value	Final value	%
5	0.41 x D	0.37 x D	- 9.75
7	0.39 x D	0.41 x D	+ 5.13
10	0.35 x D	0.36 x D	+ 2.86

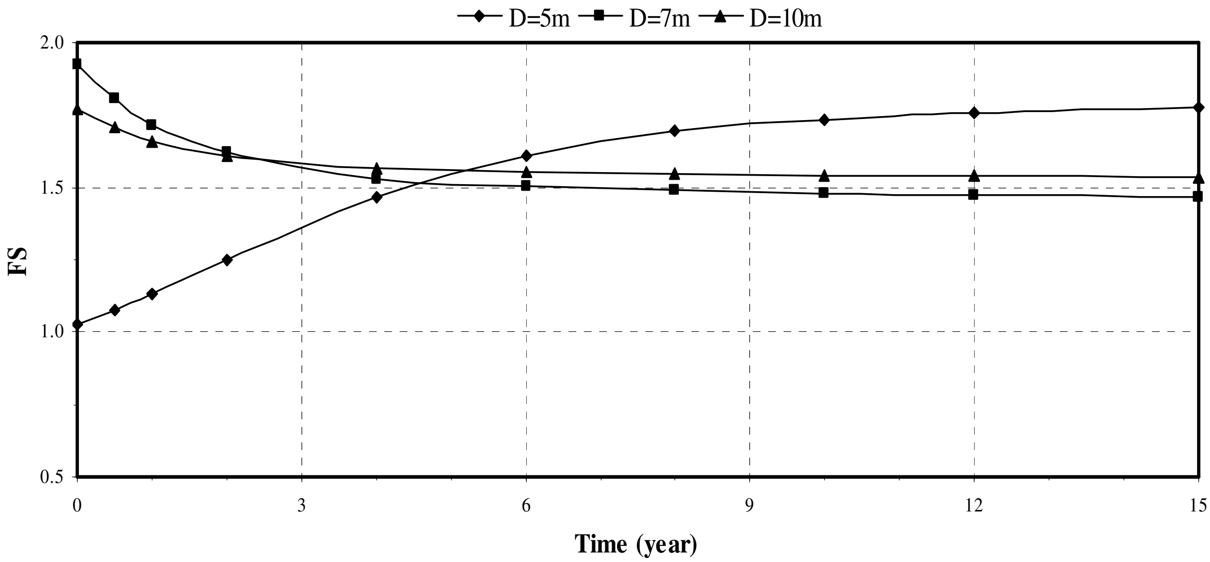


Figure 8. Factor of safety against sliding during the time of consolidation for the three wall heights.

follows:

$$(F.S.)_{sliding} = \frac{sliding\ resistance\ force}{sliding\ force} \quad (1)$$

Whereas the sliding resistance force is the product of the total downward force on the base of the wall and the coefficient of friction between the base of the retaining wall and the underlying soil. The sliding force is typically the horizontal component of lateral earth pressure exerted against the wall by backfilling material (Liu and Evett, 2008).

The factor of safety against sliding is shown in Figure 8 for the three wall heights during the time of consolidation. It can be noticed that the factor of safety will increase for (D = 5 m) and decrease for (D = 7 m) and (D = 10 m) until reaching a constant value which is approximately the same for all heights at about 6 years and its value is in the range of (1.6 to 1.8). The percent of increase or decrease in the value of the factor of safety against sliding is shown in Table 6.

Because overturning force tends to occur about the toe of the wall, the factor of safety against overturning is determined as (Liu and Evett, 2008).

$$(F.S.)_{O.T.} = \frac{\sum righting\ moment\ about\ the\ toe}{\sum overturning\ moment\ about\ the\ toe} \quad (2)$$

Figure 9 shows the variation of the factor of safety against overturning with time. The factor of safety will increase for (D = 5 m) and decrease for (D = 7 m) and (D = 10 m). The percent of increase or decrease in the value of factor of safety against overturning is shown in Table 7.

From Tables 6 and 7, it is clearly seen that the factor of safety against sliding is more critical than that against overturning (for the wall geometry taken in the analysis).

Effect of Poisson's ratio and permeability

It was found from the study carried by Matsuo et al. (1978) that the behaviour of the retraining wall is sensitive to the variation in the values of Poisson's ratio used for the backfilling material. Therefore, it is believed that the effect of Poisson's ratio for the foundation soil is also important to be studied. Since this work deals with the time-dependent behaviour, thus, the effect of the

Table 6. Change in the factor of safety against sliding.

Wall height (m)	Initial value	Final value	%
5	1.03	1.77	+ 71.8
7	1.93	1.46	- 24.4
10	1.77	1.54	- 13.0

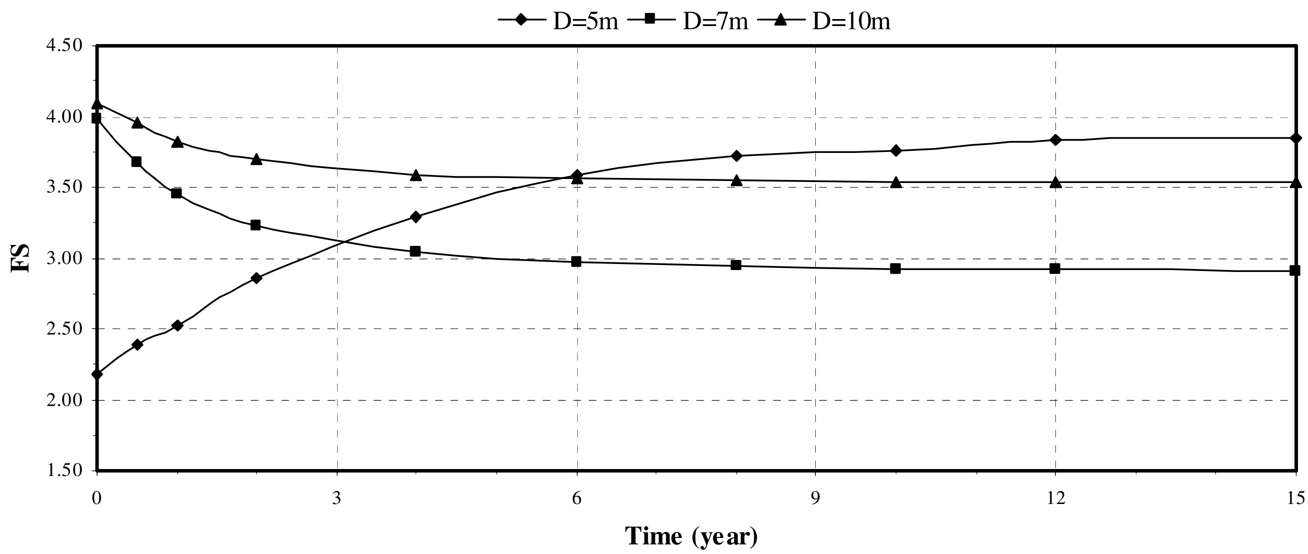


Figure 9. Factor of safety against overturning during the time of consolidation for the three wall heights.

Table 7. Change in the factor of safety against overturning.

Wall height (m)	Initial value	Final value	%
5	2.18	3.84	+ 76.1
7	4.00	2.91	- 27.3
10	4.10	3.53	- 13.9

foundation soil permeability must be studied also. In this section, the behaviour of the retaining wall, 10 m high, will be studied after 2 years from the load application of the backfilling material.

Effect of Poisson's ratio

Figure 10 shows the lateral wall movement due to three different values of Poisson's ratio for the foundation soil. It is seen that the wall movement increases as Poisson's ratio increases in value. It is obvious that the behaviour of the retaining wall is influenced by the variation of the Poisson's ratio values of the foundation soil.

The resultant earth pressure and its location during consolidation are shown in Figures 11 and 12, respectively, whereas, the factor of safety against sliding and overturning are shown in Figures 13 and 14, respectively.

It is obvious that Figures 11 to 14 are related to each other, as the lateral wall movement increases, the active earth pressure will increase causing an increase in the earth pressure resultant and its location and decrease in the factor of safety against sliding and overturning will decrease. The reason for all this behaviour is the increase in Poisson's ratio which means an increase in lateral strain and decrease in vertical strain.

Effect of permeability

The permeability of the foundation soil will influence the behaviour of the retaining wall. Figure 15 shows that the lateral wall movement decreases as the permeability

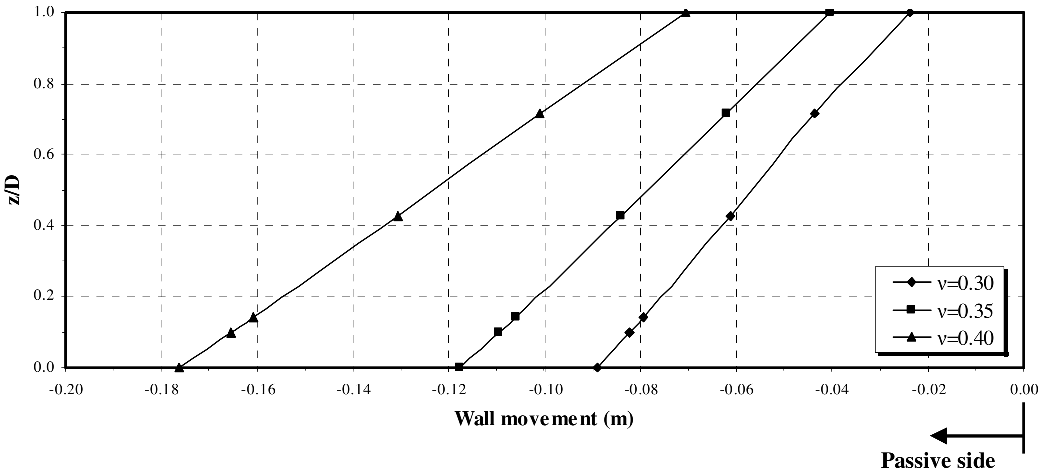


Figure 10. Effect of Poisson's ratio on the lateral wall movement after 2 years from load application (10 m wall height).

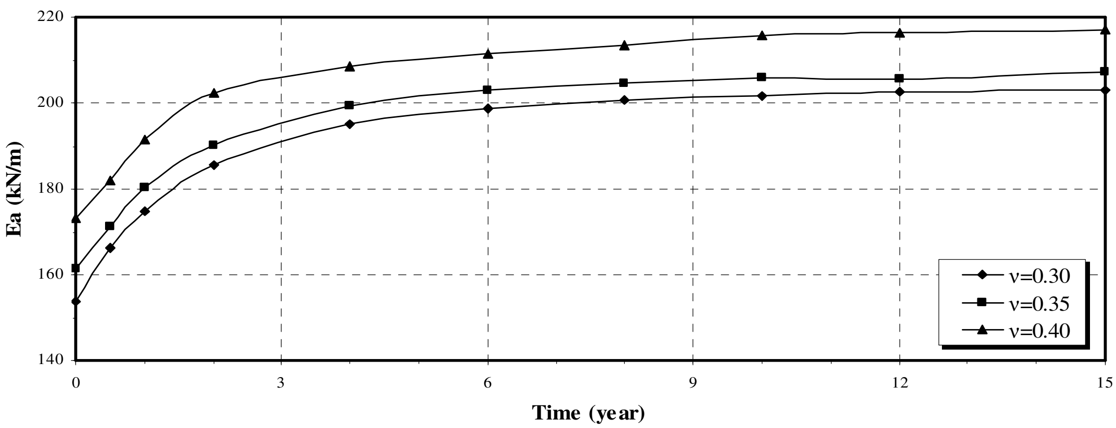


Figure 11. Effect of Poisson's ratio on the resultant earth pressure during the time of consolidation (10 m wall height).

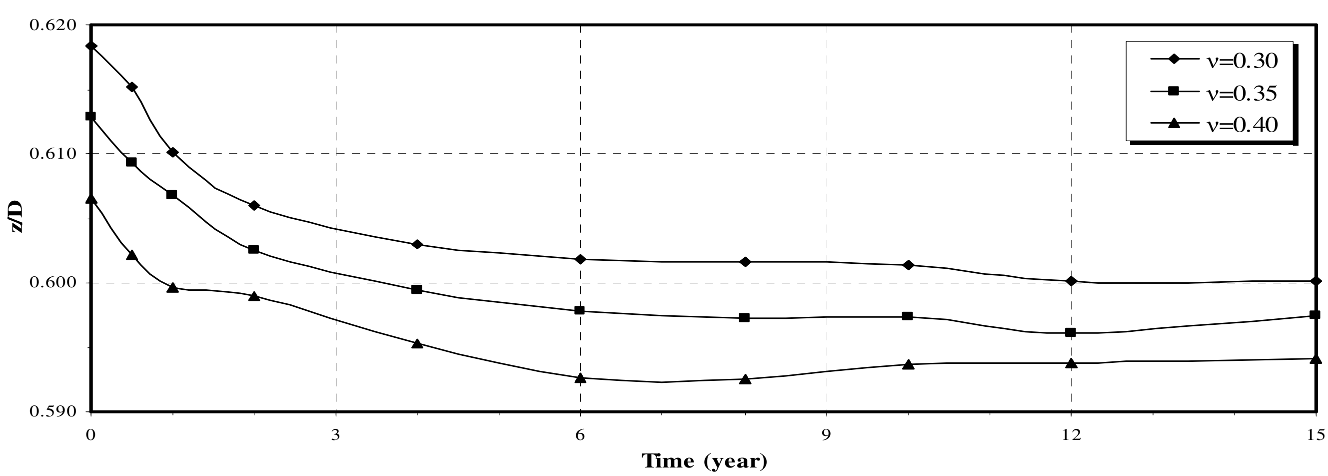


Figure 12. Effect of Poisson's ratio on the locationof the resultant earth pressure during the time of consolidation (10 m wall height).

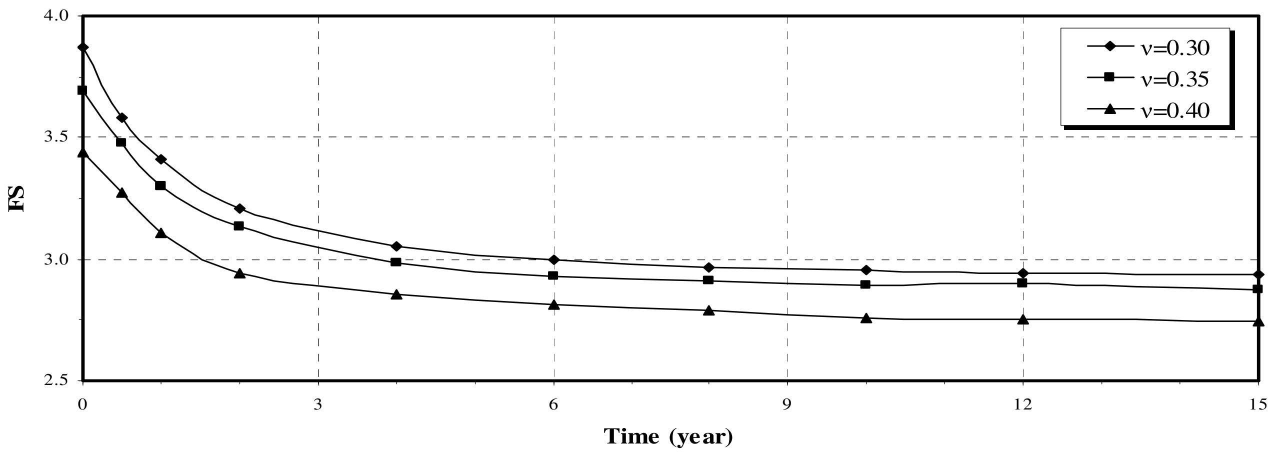


Figure 13. Effect of Poisson's ratio on the factor of safety against sliding during the time of consolidation (10 m wall height).

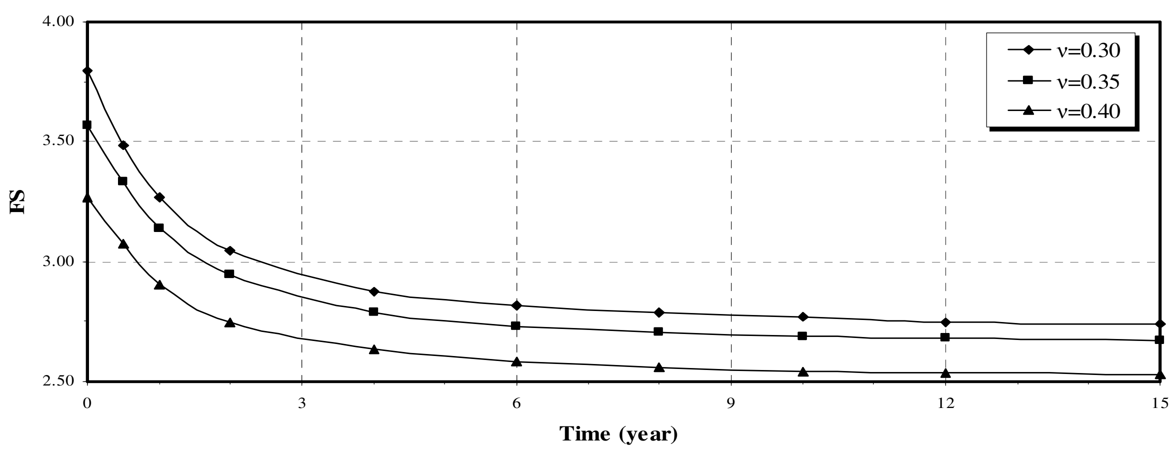


Figure 14. Effect of Poisson's ratio on the factor of safety against overturning during the time of consolidation (10 m wall height).

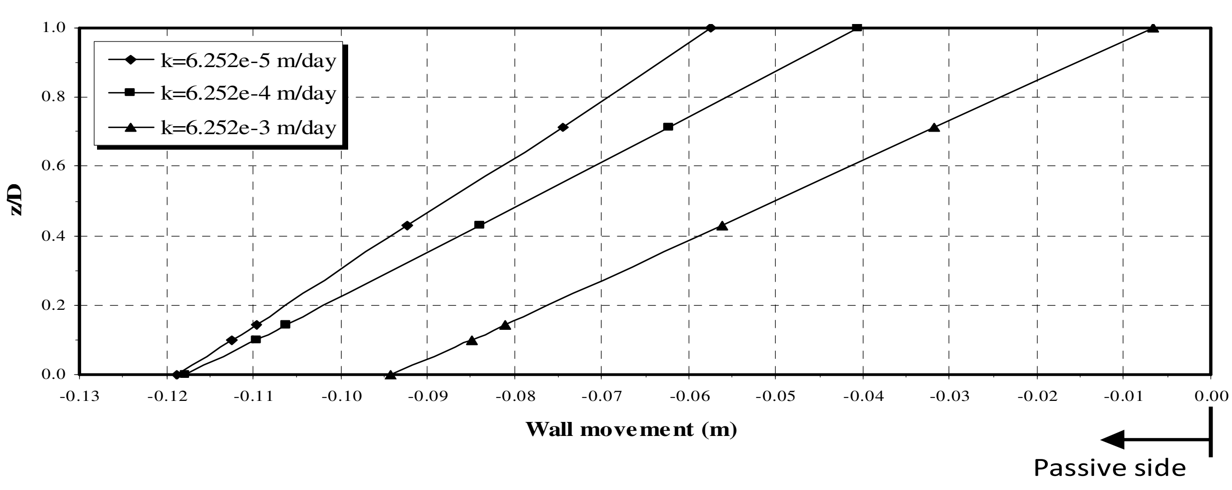


Figure 15. Effect of permeability on the lateral wall movement after 2 years from load application (10 m wall height).

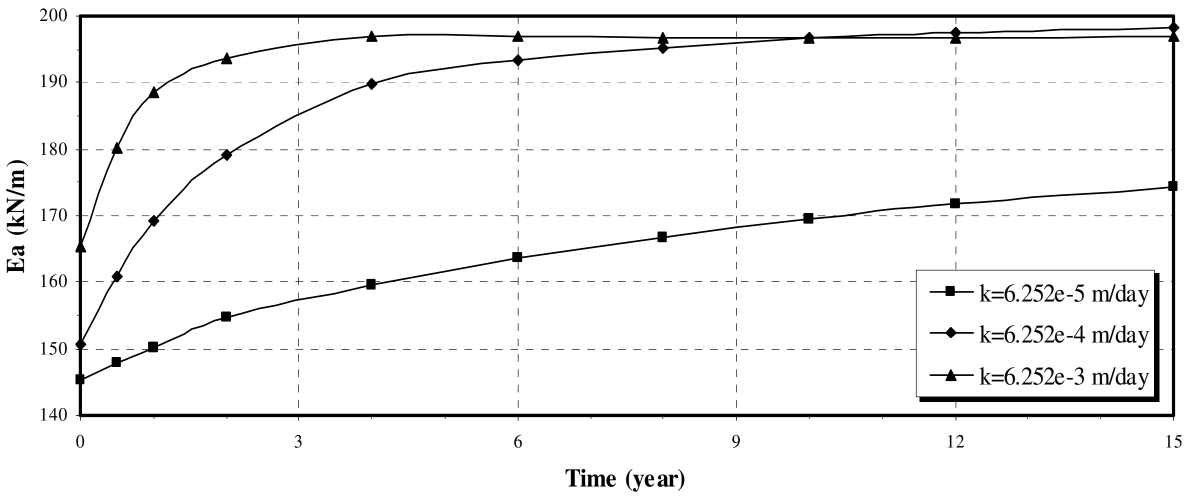


Figure 16. Effect of permeability on the earth pressure resultant during the time of consolidation (10 m wall height).

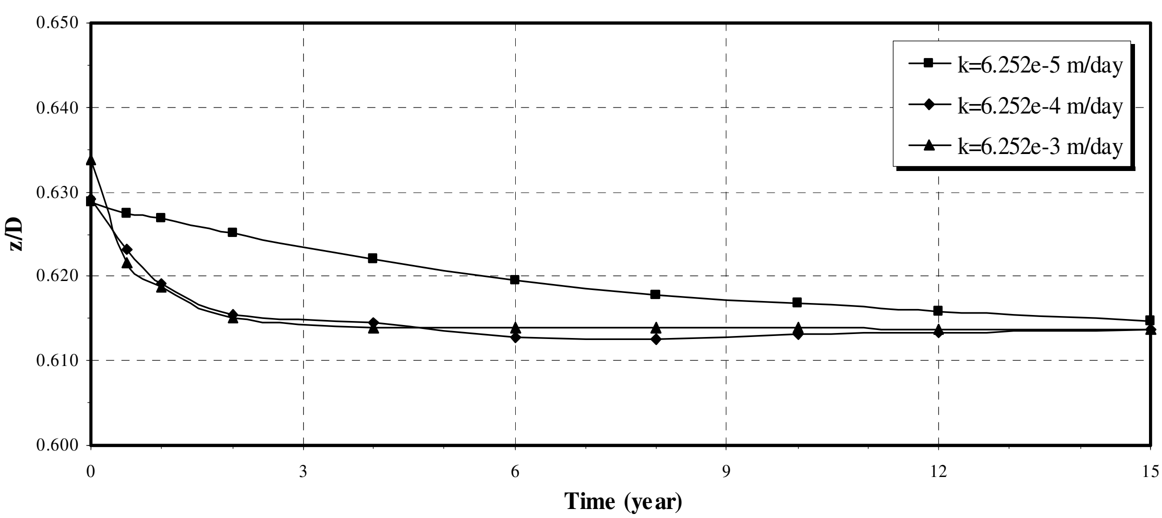


Figure 17. Effect of permeability on the location of the earth pressure resultant during the time of consolidation (10 m wall height).

increases. It can be seen that the wall movement is in the passive side and the negative sign is used in the x-axis to indicate this direction. Figures 16 and 17 shows the earth pressure resultant and its location during the time of consolidation. It is clearly seen that the earth pressure resultant at a certain time is influenced by the value of permeability, but it will reach the same value for all values of permeability at the end of consolidation time. Figures 18 and 19 show the factor of safety against sliding and overturning, respectively. The factor of safety whether against sliding or overturning will reach its steady state value within about 4 to 6 years with high foundation permeability, whereas, for low permeability case, it needs a longer time to reach its steady state value.

Conclusions

The results of the finite element analysis show that the wall constructed on compressible stratum will tilt towards the backfill, rather than away from the backfill as the classical earth pressure theories indicate. This results in earth pressure forces from the finite element analysis greater than those computed by using the classical earth pressure theories (Rankine and Coulomb). This performance (type of movement) is attributed to the incorporation of the compressibility of the soil foundation and the non-uniform loading on the soil foundation.

In designing a wall-soil system, attention should be given to the factor of safety against sliding which is more

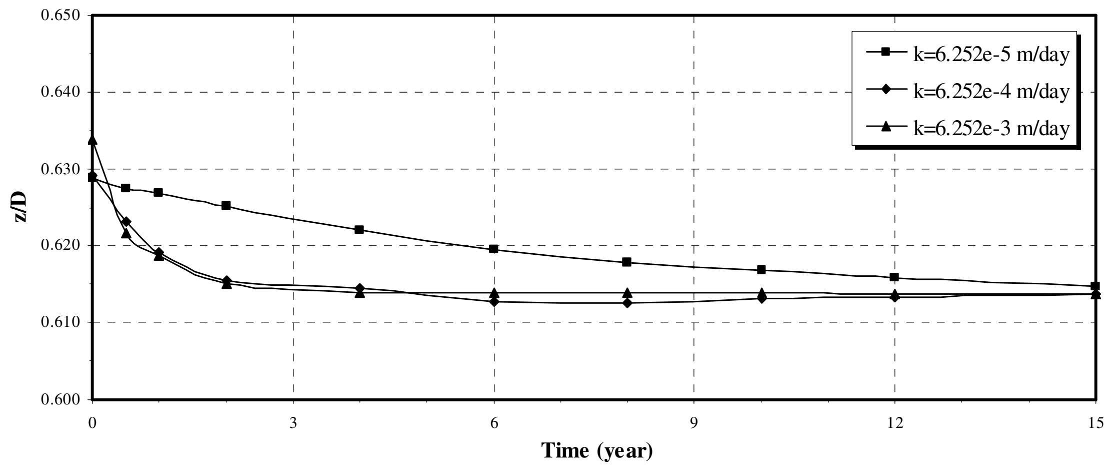


Figure 18. Effect of permeability on the factor of safety against sliding during the time of consolidation.

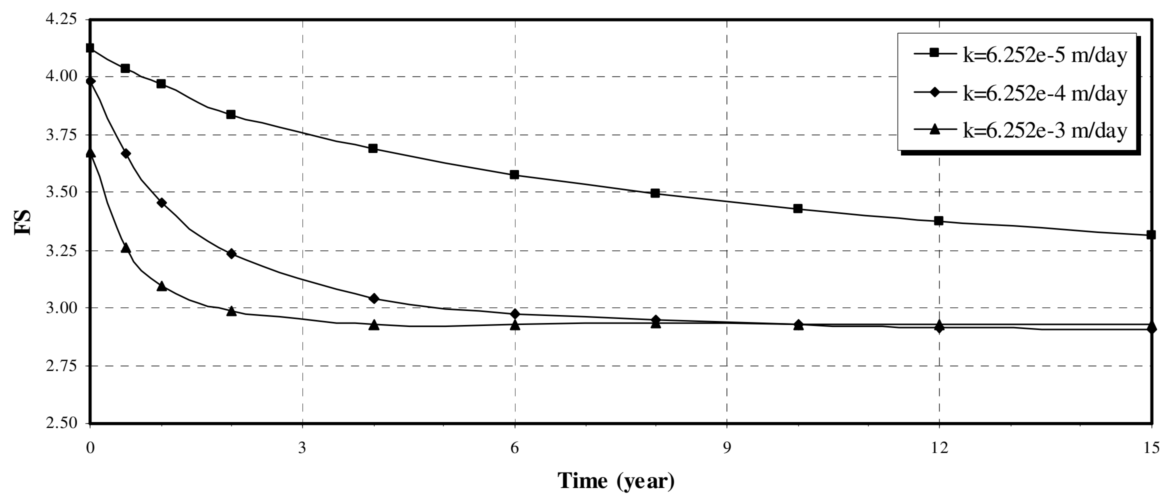


Figure 19. Effect of permeability on the factor of safety against overturning during the time of consolidation.

critical than the factor of safety against overturning for the types of walls considered in this analysis.

Although the behaviour of the 7 and 10 m high retaining walls is expected, the behaviour of 5 m high was unexpected. Therefore, the effect of wide variation of height of retaining walls on the behaviour of wall constructed on compressible strata needs to be investigation in more details.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues Prof. Dr. Yousif J. Al-Shakarchi from the University of Baghdad and Prof. Dr. Husain M. Husain from the University of Technology, Baghdad, Iraq, for many valuable discussions and assistance in the interpretation of the data as presented in this paper.

REFERENCES

Bhatia SK, Bakeer RM (1989). Use of the finite element method in modeling a static earth pressure problem. Int. J. Num. Anal. Methods Geomech., 13(2): 207-213.

Britto AM, Gunn MJ (1987). Critical State Soil Mechanics Via Finite Elements. Ellis Horwood Limited.

Clough GW, Duncan JM (1969). Finite Element Analyses of Port Allen and Old River Docks, Contract Report S-69-6, U.S. Army Engineers, Waterways Experiment Station, Vicksburg, MS.

D'Appolonia DJ, Lambe TW, Poulos HG (1971). Evaluation of pore pressures beneath an embankment. J. Soil Mech Found. Eng. Div., ASCE, 97(SM6): 881-897.

Desai CS, Zaman MM, Lightner JG, Siriwardane HJ (1984). Thin-layer element for interfaces and joints. Int. J. Num. Anal. Methods Geomech., 8(1): 19-43.

Ebeling RM (1990). Review of Finite Element Procedures for Earth Retaining Structures, Miscellaneous paper ITL-90-5, U.S. Army Crops of Engineers, Waterways Experiment Station, Washington DC.

Gourvenec SM, Powrie W (1999). Three-dimensional finite-element analysis of diaphragm wall installation. Geotechnique, 49(6): 801-823.

Lambe TW, Whitman RV (1979). Soil Mechanics. SI Version. John Wiley & Sons, India.
Liu C, Evett JB (2008). Soils and Foundations. 7th edition. Pearson Prentice Hall.
Matsuo M, Kenmochi S, Yagi H (1978). Experimental study on earth pressure of retaining wall by field test. Soil Mech. Found. Eng., 18(3): 27-41.
McCarron WO, Chen WF (1987). Application of a bounding surface model to Boston blue clay. Comput. Struct., 26(6): 887-897.
Potts DM, Fourie AB (1984). The behavior of a propped retaining wall: Results of a numerical experiment. Geotechnique, 34(3): 383-404.
Potts DM, Fourie AB (1986). A numerical study of the effect of wall deformation on earth pressures. Int. J. Num. Anal. Methods Geomech., 10(4): 383-405.
Skempton AW, La Rocheele P (1965). The Bradwell slip: A short term failure in London clay. Geotechnique, 15(3): 221-242.
St. John HD (1975). Field and Theoretical Studies of the Behavior of Ground around Deep Excavation in London Clay. Ph.D. Thesis. Univ. of Cambridge, Cambridge, U.K.